Comparison of Organic and Inorganic Nitrogen Sources for Rice[1]

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ABSTRACT

Rice (*Oryza sativa* L.) responds well to green manure-N under flooded conditions, but more quantitative data are needed for comparisons to inorganic N. This study compared the effects of vetch (*Vicia benghalensis* L.) and $(NH_4)_2SO_4$ on patterns of N availability and plant uptake, applied-N recovery at harvest, and grain yield in flooded rice culture. The sources were incorporated in a Clear Lake clay (Typic Pelloxerert) in factorial combination of 60 kg N/ha increments up to a maximum rate of 180 kg N/ha. Grain yields were determined in plots of 18.9 m^2 while N balance was assayed in microplots (0.27 m^2) treated with ^{15}N-labeled materials. Ammonium sulfate was more effective in raising extractable-N concentrations early in the growing season and made a greater contribution to plant N status throughout the season. There was no evidence that vetch extended the period of N availability to plants. Grain yields were highly dependent on N uptake; they maximized at 10.1 Mg/ha with 120 kg N/ha as $(NH_4)_2SO_4$ but responded linearly to vetch up to 8.4 Mg/ha with the highest rate of addition. Ammonium sulfate effected greater labeled-N recovery (19% across rates) and apparent N recovery (55.6%) by plants than vetch (10.1 and 27.9%, respectively). More vetch-N was recovered in the soil at harvest; total recoveries were, therefore, not significantly different between N sources. The rate of green manure-N mineralization early in the growing season appears to be the limiting factor in comparison to inorganic N.

Additional index words: **Ammonium sulfate, Available nitrogen, Nitrogen-15, Nitrogen uptake, *Oryza sativa* L., Vetch, *Vicia benghalensis* L., Yield.**

GREEN manure sources of N are usually equivalent to chemical sources in affecting N uptake and yield of lowland rice (*Oryza sativa* L.) when applied at moderate rates of 30 to 40 kg N ha^{-1} (11,12,13,14,19,20,25,26), although the chemical sources (containing ammoniacal N) appear to gain an advantage at rates of addition currently considered necessary for optimal yields (21,22). Central to a comparison between the sources is the necessity for the green manure source to undergo a period of decomposition during which the added N is gradually made available, in contrast to the chemical source where the N is immediately so. Previous studies have followed the patterns of N availability as affected by green manure and chemical sources under flooded soil conditions in pots or incubation studies without plants (18,20,24) and have shown the gradual increase with the former and the decrease with the latter. Results are contradictory, however, as to whether N availability with the green manure source ever equals or exceeds that with an equivalent chemical source.

There have been no field studies with flooded rice that monitored and compared the patterns of N availability due to the two sources, nor have there been field tracer studies that utilized labeled materials allowing specific identification of N recovery. The purpose of this study was to compare a green manure source of N to a mineral source for flooded rice at varying rates of addition, alone and in combination. Labeled materials were utilized to trace the appearance of N from the two sources in the available form and its recovery in the plant-soil system at harvest.

MATERIALS AND METHODS

The experiment was conducted on a Clear Lake clay soil (fine, montmorillonitic, thermic Typic Pelloxerert; 27.9 g/kg organic matter, 1.1 g/kg N, C/N ratio 14:1, pH 6.7). The two sources of N utilized were vetch (*Vicia benghalensis* L.) and $(NH_4)_2SO_4$. The vetch applied to the main plots (30.3 g/kg N) had been grown at another location the preceding winter and was chopped with a flail mower, collected in burlap sacks, and oven dried 2 weeks prior to application. The ^{15}N-labeled vetch applied to microplots (44.0 g/kg N, 3.32 atom % excess ^{15}N) was grown in ^{15}N-labeled solution culture and was harvested, oven dried, and ground (1-mm mesh) 1 week prior to application. The $(NH_4)_2SO_4$ applied to main plots was commercial grade; that applied to microplots was labeled with 5.35 atom % excess ^{15}N.

The two sources were factorially applied to main plots in

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60 kg N/ha increments up to a maximum rate of 180 kg N/ha. An untreated check was included. A randomized, complete block design with three replications and a plot size of 3.1 by 6.1 m was utilized. The materials were spread by hand over the surface of the plots and disked under to a depth of ~10 cm.

Aluminum cylinders (58.4-cm diam, 35-cm length) were installed by removing the soil down to the plowpan (20 cm), placing the cylinders in the holes, and refilling with soil. Nitrogen-15-labeled materials were applied to the microplots at rates of 60 or 120 kg N/ha of each source alone, or 60 kg N/ha of each source combined. Duplicates of the latter treatment were included, one receiving labeled vetch and unlabeled $(NH_4)_2SO_4$ and the other, vice versa. These materials were placed at a depth of 10 cm in the soil. No labeled sources were utilized at the 180 kg N/ha rate of addition.

The field was flooded 3 days after the completion of treatment application and was aerially sown with a medium-grain, short-statured commercial rice variety ('M-101'). A uniform plant population was realized but some seedlings were transferred to the rings to ensure an adequate stand within these areas.

Soil and Plant Sampling

Soil and plant samples were taken at 30, 45, 60, and 100 days after seeding and at harvest (153 days). Soil samples were taken with a soil core sampler (3-cm diam) to a depth of 15 cm from each ring and main plot area. Three samples from each plot or ring were composited and stored at 10°C until extraction within 3 days. Four whole plants (aboveground portion) were taken from each plot or ring area at each sampling date except harvest, when the entire ring (microplot) area or a 0.19-m^2 subsample from the macroplot area were taken. The plant samples were oven dried, weighed, and stored for later analysis.

Soil Analysis

A subsample (80 g) of saturated soil was weighed into a 125-mL Erlenmeyer flask, a 50-mL aliquot of 2 *M* KCl was added, and the flasks were stoppered and shaken mechanically for 1 h. Samples were extracted by filtration under suction through No. 2 Whatman filter paper (Whatman, Inc., Clifton, NJ) and washed with 150 mL of 1 *M* KCl. The filtrates were transferred to 250-mL volumetric flasks and brought to volume.

Duplicate 50-mL aliquots of each filtrate were analyzed for ammonium by steam distillation with MgO. Separate duplicates were steam distilled with MgO and Devarda alloy to determine ammonium plus nitrate. The distillates were collected in 5 mL of 0.3 *M* H_3BO_3-indicator solution, titrated with standard HCl, and saved for ^{15}N-analysis by mass spectrometry.

The soil remaining after extraction was dried and crushed to pass a 1-mm sieve. Residual N was determined by digesting weighed (2-g) samples of the extracted soil in micro-Kjeldahl flasks with 5 mL of concentrated H_2SO_4 and approximately 3 g of K_2SO_4-catalyst mixture. Steam distillation was carried out with 15 mL of 12.5 *M* NaOH and the samples otherwise treated as above for the soil extracts.

Clay-fixed ammonium was determined as described by Dhariwal and Stevenson (6) on the extracted soils. The titrated samples were saved for ^{15}N analysis. Organic N was determined by subtracting the clay-fixed amount from the residual amount.

Plant Analysis

Plant samples taken during the season were dried, weighed, and ground to pass through a 0.5-mm sieve. Samples taken at harvest were separated into grain and straw before grinding. Samples (0.2 g) of the finely ground material were digested and steam distilled as described above for the residual soil-N determination and saved for ^{15}N analysis.

Yield Determination

A middle portion (13 m^2) of each plot was mechanically harvested 153 days after planting. The harvested grain was weighed at time of harvest and subsampled for moisture determination.

Data Analysis

The data were analyzed using analysis of variance procedures, and LSDs were calculated where significance was indicated by *F*-tests. The soil-^{15}N data could not be analyzed statistically in several instances where levels of labeling dropped so low as to require a combination of replications for analysis. The clay-fixed ^{15}N and soluble + exchangeable ^{15}N fell into this category so these data are provided for comparison without statistical consideration. Otherwise, all of the plant-^{15}N data, the soil organic-^{15}N data, and the soil-^{15}N data at harvest were analyzed according to analysis of variance. The ^{15}N data at harvest were analyzed as a multifactorial design, with the two sources as one factor and the 60, 120, and 60 + 60 kg N/ha rates as a second factor. This allowed direct comparisons between the two sources as to recovery in the soil-plant system. Regression analyses were performed with the MSUSTAT statistical program (10).

RESULTS

Behavior of Nitrogen in Soil

Measurements of KCl-extractable NH_4^+-N are intended to reflect the amount of N readily available for plant use at time of sampling. This parameter includes mineral N both in solution and on the exchange complex that can readily replace N removed from solution by uptake, immobilization, and various mechanisms of loss from the system. This fraction will be referred to here as extractable N and represents NH_4^+-N since no NO_3^--N was detected at any point in the sampling and analytical procedure, typical for a flooded soil.

Concentrations of extractable N measured in areas receiving labeled materials showed significant differences only at the first sampling date (day 30, Fig. 1). Concentrations were greater with increasing rates of N addition and with $(NH_4)_2SO_4$ compared to vetch. This trend held for total (labeled and unlabeled) and labeled N. The effectiveness of each treatment in raising the concentration of extractable N over that of the control is greater than can be directly attributed to levels of labeled NH_4^+-N. For example, while 14 μg/g of labeled N was extractable at day 30 in the 120 kg $(NH_4)_2SO_4$-N/ha treatment, total available N was 43 μg/g. This means that 29 μg/g of unlabeled soil-N was in the extractable form in this treatment compared to 8 μg/g in the untreated control. This is a manifestation of the *priming effect*, or apparent stimulation of soil-N mineralization, due to N addition (24).

When the two sources were added together at equal rates (Fig. 1), the concentration of total extractable N at day 30 (41 μg/g) was very nearly equal to the sum of the concentrations of the two sources added alone (46 μg/g), with no apparent effect of one source on the other in terms of labeled-N extractability.

Total extractable N for all treatments dropped to a value of 6 μg/g by day 45, uniformly declined to 3 μg/

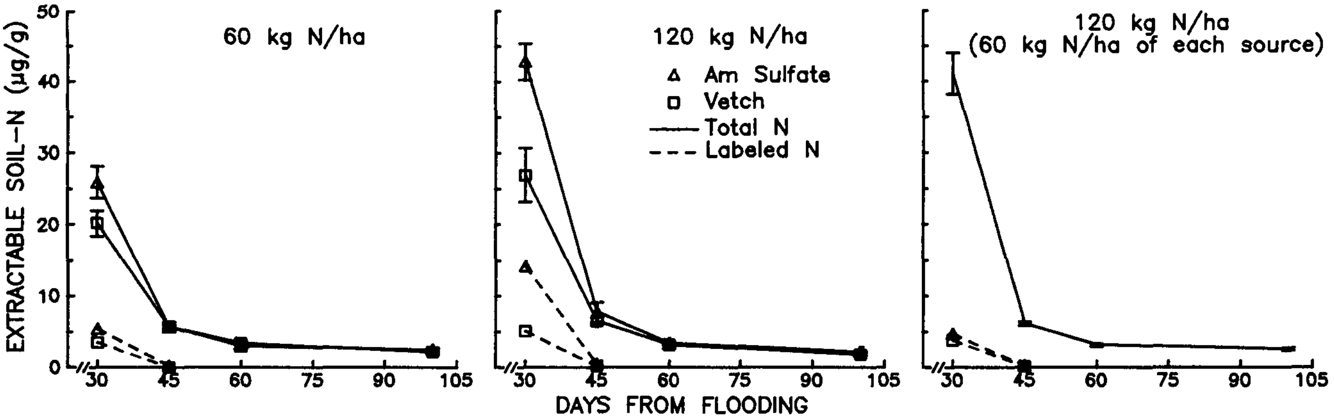

Fig. 1. Concentrations of KCl-extractable NH_4^+-N in soil as a function of time from flooding as affected by rates and sources of N addition. Control value at 30 days = 8 µg/g. Vertical bars represent SE of means.

g by day 60, and showed little variation throughout the remainder of the season. Labeled extractable N was undetectable by 45 days after flooding.

The detection of labeled N in the organic fraction (Fig. 2) indicated continued mineralization of vetch-N and perhaps remobilization of $(NH_4)_2SO_4$-N from day 30 to day 45. Values for both sources and rates varied throughout the remainder of the season, but at harvest (Table 3), labeled organic N was proportional to the added rates and was higher for the vetch source as compared to $(NH_4)_2SO_4$.

No significant differences were detected in the concentration of clay-fixed N among treatments (Table 1). The scant levels of labeling in this fraction required the combination of samples for ^{15}N-analysis so no statistical treatment can be performed on these data. There was a slight trend for increased fixation of $(NH_4)_2SO_4$-N, but the low concentrations indicate this to be a minor mechanism of N loss in this study.

Plant Nitrogen

Plant N (g N/kg, plant tops, dry-weight basis) at day 30 ranged from 16.5 to 32.5 g/kg in areas treated with labeled materials (Table 2) and were as high as 35.0 g/kg in the main plot of the 180 kg $(NH_4)_2SO_4$-N/ha treatment. Concentrations dropped asymptotically thereafter and tended to converge, but significant differences between treatments were detected throughout the growing season. Plant N was obviously increased by increasing rates of N addition and by the $(NH_4)_2SO_4$ source over the vetch at the higher rate of addition, reflecting the trend in extractable N.

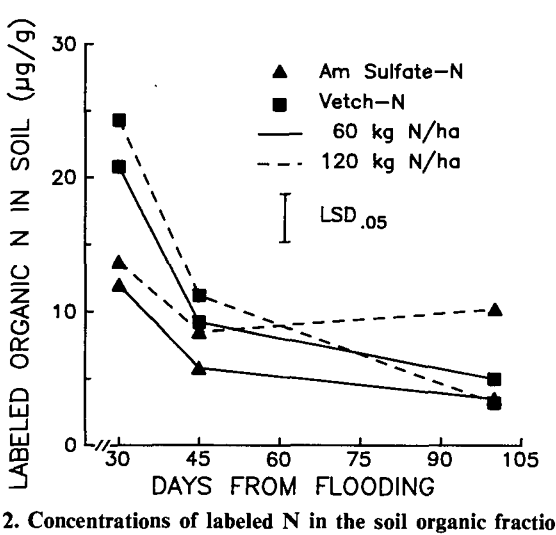

Fig. 2. Concentrations of labeled N in the soil organic fraction as affected by two N sources added separately at two rates.

Labeled N contributed 32 to 51% of the total N taken

Table 1. Clay-fixed N at various sampling dates as affected by rate and source of addition.

N application		N	Days from flooding		
Rate	Source†	fraction‡	30	100	Harvest
kg N/ha			mg N/kg soil		
0	V	Total	142	161	184
60	V	Total	145	160	164
		NDFV	0.8	0.3	0.5
120	V	Total	146	143	164
		NDFV	1.7	0.7	1.6
60	AS	Total	149	159	176
		NDFAS	1.8	--	0.9
120	AS	Total	151	159	174
		NDFAS	2.1	--	1.0
60 + 60	V + AS	Total	151	161	172
		NDFV	0.8	--	0.6
		NDFAS	1.8	0.3	1.1
	$LSD_{0.05}$	Total N	NS	NS	NS
	CV (%)	Total N	1.8	3.1	2.2

† V, vetch; AS, ammonium sulfate.

‡ NDFV, N derived from vetch; NDFAS, N derived from ammonium sulfate.

Table 2. Plant N concentrations at various sampling dates as affected by rate and source of N addition.

N application		Days from flooding				
Rate	Source†	30	45	60	100	Harvest
kg N/ha		g/kg				
0		16.5	13.5	11.5	5.5	5.7
60	V	24.2	17.8	10.8	5.9	5.4
120	V	28.9	21.2	12.8	6.0	5.8
60	AS	30.6	21.1	11.8	5.7	5.3
120	AS	32.5	27.2	15.8	7.2	6.3
60 + 60	V + AS‡	32.3	25.9	15.1	7.0	5.7
	$LSD_{0.05}$	3.4	4.9	1.9	0.8	0.4
	CV (%)	3.9	7.4	4.6	3.9	2.2

† V, vetch; AS, ammonium sulfate.

‡ Values in this row represent the averages for the ^{15}V + AS and the V + ^{15}AS treatments.

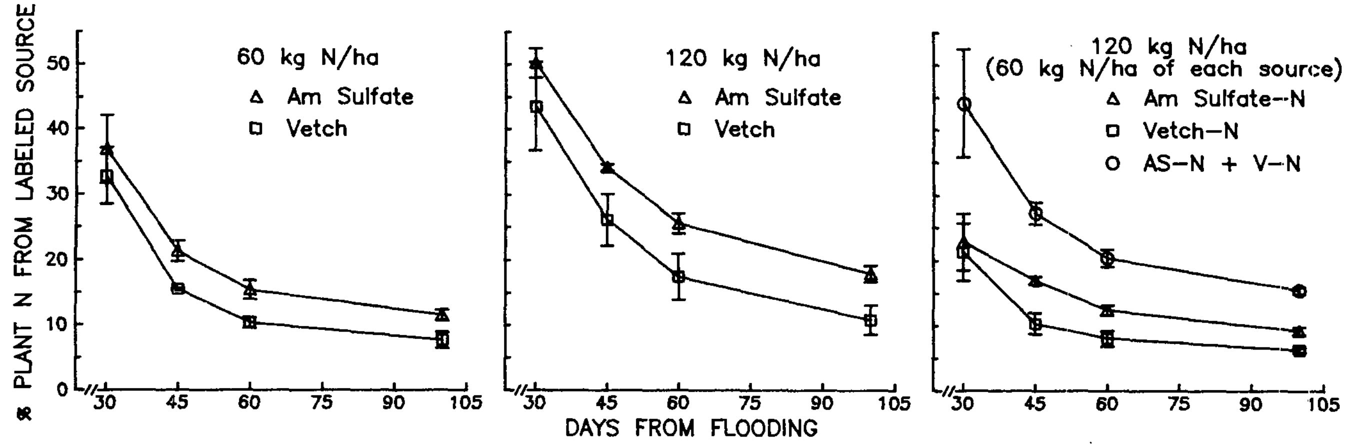

Fig. 3. Relative contribution of N from the added source to the total N status of rice plants as a function of time from flooding. Vertical bars represent SE of means.

up by plants at day 30 (Fig. 3). As the season progressed and labeled N became increasingly unavailable (Fig. 1), plants became more dependent on soil-N mineralization for uptake and labeled plant-N was subsequently diluted. This dilution of labeled plant-N proceeded rapidly from day 30 to day 60 and none of the treatments appears to have slowed this decline in comparison to the others. There is, therefore, no evidence that either N source was able to provide a more continuous supply of N during this time span.

Grain Yields

Whole-plot grain yields responded very well to N fertilization from both sources (Fig. 4). From a control level of 5.30 Mg/ha [120 g/kg (w/w) moisture], yields increased to 8.43 Mg/ha with the addition of 180 kg vetch-N/ha and were maximized at 10.10 Mg/ha with 120 kg $(NH_4)_2SO_4$-N/ha. Where the two sources were combined at a total rate of 120 kg N/ha, yields were intermediate to the two sources alone. The two combination treatments of 180 kg N/ha were as effective as $(NH_4)_2SO_4$.

The grain yields obtained from the microplots and subsamples within macroplots were regressed against whole-plot yields to test the validity of using these data to assess treatment effects. The regression equation was calculated as $y = -457.7 + 1.165\,x$, $r^2 = 0.71$, $P < 0.01$, where y = microplot or subsample grain yield, and x = whole plot grain yield, both variables expressed as kg/ha. The significant relationship between the two variables lends confidence to the assumption that microplots reflected whole plot effects, but slightly underestimated yields below 2.8 Mg/ha and overestimated yields above this value (about 12% overestimate at maximum yield).

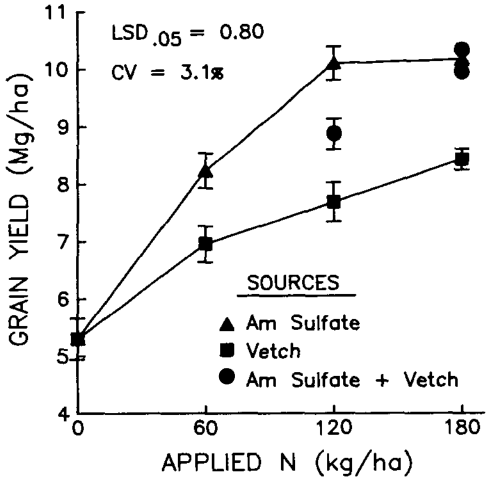

Fig. 4. Rice grain yields [120 g/kg (w/w) moisture] as affected by rates and sources of addition. The cluster of points at 180 kg N/ha representing AS alone, 2/3 AS + 1/3 V, and 1/3 AS + 2/3 V did not differ significantly. Vertical bars represent SE of means.

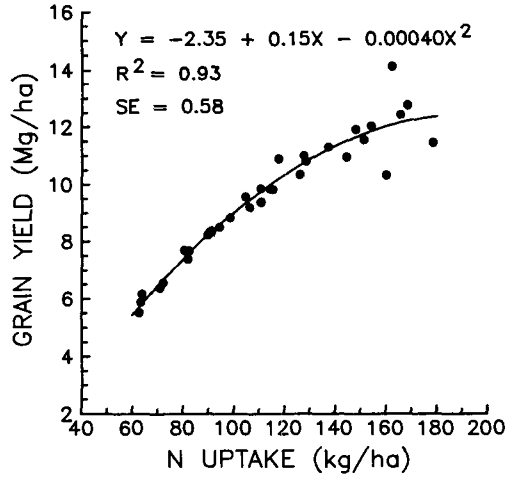

Fig. 5. Relationship between rice grain yield and total aboveground plant N uptake.

Grain yields reflect treatment effects on N availability and plant-N status early in the season, but consideration should be given to season-long effects. The dilution of labeled N in the plants is indicative of continued N uptake throughout the season; the dependence of grain yield on total N accumulation is shown in Fig. 5 (these data were taken from subsamples within whole plots, so grain yields tend to be higher than those reported in Fig. 4). This relationship confirms that treatment effects on grain yield were due to effects on N availability and uptake, and offers additional insight on the relationship between yield and N uptake. Solution of the regression equation for $y = 0$

indicates a minimum uptake of 16 kg N/ha to realize any yield at all. Solution of the derivative, $dy/dx = 0.153 - 0.000796x$, predicts a maximum yield of 12.43 Mg/ha dependent on the uptake of 192 kg N/ha.

Nitrogen Uptake and Recovery

Recovery of added N in the aboveground portion of the plants ranged from about 10% of the added amount for all vetch treatments to 24.3% for the 120 kg $(NH_4)_2SO_4$-N/ha treatment (Table 3). These are relatively low rates of recovery for added N compared to upland crops, but are typical for flooded rice. They also stand in contrast to the effective yield increases due to treatments and should be compared to apparent N recoveries (Table 3). The apparent rate of recovery was computed as the increase in total N uptake over the control due to treatments. Uptake of unlabeled N was stimulated by all treatments except the lowest rate of vetch addition. For example, uptake of unlabeled soil-N was 69.5 kg N/ha for the control and over 100 kg N/ha for the 120 kg $(NH_4)_2SO_4$-N/ha treatment. This reflects the apparent stimulation of soil-N mineralization by the addition of labeled N found early in the season, through either a real priming effect or through isotopic substitution (see Discussion).

The regression of N uptake versus N applied (Fig. 6) reveals a 56% apparent rate of recovery for $(NH_4)_2SO_4$ compared to 28% for vetch. This confirms the ^{15}N data in that $(NH_4)_2SO_4$-N was recovered by plants at more than twice the rate of vetch-N; it also illustrates that the effect of each treatment on N uptake, particularly at the higher rates of addition, exceeded the actual plant recovery of labeled N.

Percent recovery of labeled N in the plants was unaffected by the rate of vetch addition but increased with higher rates of $(NH_4)_2SO_4$ addition. The percent recovery of N from either source was unaffected by combination with the other at the 60 kg N/ha rate.

Recovery of labeled N in the soil at harvest was greater in the vetch treatments than in the $(NH_4)_2SO_4$ treatments (Table 3). This is indicative of the incomplete mineralization of vetch-N, a partial explanation for the lower efficacy of this material, and also points to the potential residual effect of the organic source.

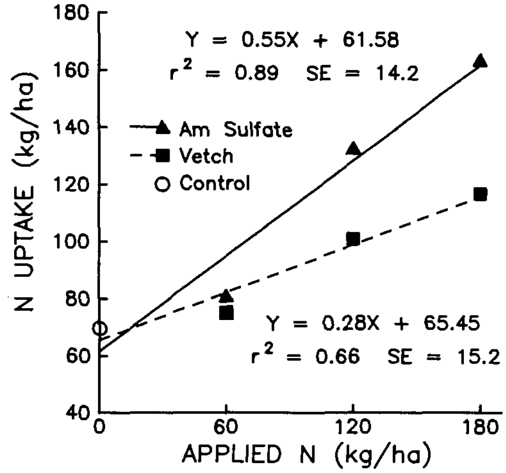

Fig. 6. Relationship between total aboveground plant N uptake and rate of application for two N sources.

More complete recovery of labeled soil-N may have been realized with deeper sampling.

Overall recovery of labeled N in plants and soil ranged from 36 to 46% of that applied but was not significantly affected by treatments. Apparently, the higher rate of $(NH_4)_2SO_4$-N recovery by plants compensated for the higher rate of vetch-N recovery in the soil.

DISCUSSION

Vetch was not as effective as $(NH_4)_2SO_4$ as a source of N for flooded rice on this soil. The primary limitation was the rate of mineralization early in the growing season, evidenced by the greater availability of $(NH_4)_2SO_4$-N and the lower relative contribution of vetch-N to plant N status at the initial sampling date. Another indication is the greater recovery of vetch-N in the soil organic fraction at harvest. There was no greater loss of vetch-N from the soil-plant system, so its lower efficacy is traceable to plant availability. This is well illustrated in the treatments receiving 60 kg N/ha from each source, where the differential labeling technique was utilized. This treatment allows comparison of the two sources directly without the complicating factor of plant growth effects (i.e., differences in N uptake due to differences in root development and soil exploration [1]). In this case, total recoveries of the two sources at harvest were virtually identical, but of the recoverable vetch-N, only 28% was in the plant versus 44% for the $(NH_4)_2SO_4$-N.

Differences in the pattern, as opposed to absolute concentrations of N availability from the two sources,

Table 3. Nitrogen uptake and recovery in the soil-plant system at harvest as affected by rate and source of addition.

N application		N fraction‡	Plant N uptake	Recovery of added N		
Rate	Source†			Plant§	Soil	Soil + plant
kg N/ha			kg/ha	%	kg/ha	%
0		Total	69.5			
60	V	Total	75.1	9.4		
		NDFV	6.4	10.6	15.1	35.9
120	V	Total	100.8	26.1		
		NDFV	11.5	9.6	34.5	38.4
60	AS	Total	80.9	18.9		
		NDFAS	9.8	16.3	12.9	37.8
120	AS	Total	132.6	52.6		
		NDFAS	29.2	24.3	26.0	46.0
60 + 60	V + AS	Total	105.6	29.9		
		NDFV	6.7	11.2	17.1	39.8
		NDFAS	10.2	17.0	13.1	38.9
	$LSD_{0.05}$	Total N				
		Source (S)	8.9	8.7		
		Rate (R)	10.9	10.7		
		S × R	15.4	NS		
		NDFS				
		S	2.0	2.4	4.5	NS
		R	2.4	2.9	5.5	NS
		S × R	3.4	4.0	NS	NS
	CV (%)	Total N	4.7	4.0		
		NDFS	8.9	8.6	12.6	6.7

† V, vetch; AS, ammonium sulfate.

‡ NDFV, N derived from vetch; NDFAS, N derived from ammonium sulfate; NDFS, N derived from added source.

§ Values for total N represent the apparent recovery of added N. This is computed as the increase in N uptake due to treatment over the control, divided by the added amount.

were not detected due to the relatively long period of time between flooding and the first sampling (day 30), and the complicating factor of plant uptake later in the season. Previous work on the same soil (24) showed that vetch-N mineralization parallels that of soil-N, with N gradually becoming available during the initial 30 days of soil flooding but never exceeding the availability of $(NH_4)_2SO_4$-N at equal rates of addition. In the work reported here, there were no differences between treatments in the patterns of labeled-N dilution in plants, the grain yield relative to uptake, or in the distribution of N within the plant (data not shown). There was an indication of some continued mineralization of vetch-N from day 30 to day 45 based on organic-N measurements, but this had no discernable effect on the pattern of ^{15}N dilution within plants. The dilution effect may be obscured by differences in growth rate or N uptake, or both, but here again, the combination treatment (60 kg N/ha of each source with differential labeling) overcomes these limitations.

These findings differ from previous reports that green manure sources of N are equally as effective as inorganic sources for flooded rice (11,12,22,25,26). Most of these previous studies utilized lower rates of fertilization (30–40 kg N/ha), and, perhaps more importantly, other cultural practices may have differed. Such factors as cropping history (27), cultivar selection, water management or seeding method (23), N application techniques (1,26), and C/N ratio of the green manure source (26,27) could play roles in crop utilization and response to the two sources. For example, Morris et al. (11,12) found inorganic N to be of varying efficacy in relation to green manure-N for rice but concluded that the mineralization rate of green manure-N more closely matched plant uptake patterns. This contrasts with our findings that the chief effects of either source on N availability were manifested early in the season, and, in this respect, the inorganic source was superior. Nor does our data confirm their contention that inorganic N is subject to greater losses from the soil-plant system. It should be noted that their experimental conditions differed considerably as to soil type, climate (temperature effects on green manure-N mineralization are noted [24]), seeding method (transplanted seedlings versus aerial broadcast of pre-soaked seed), and N application and incorporation techniques. All of these factors are important in considering the relationship between N availability and plant uptake, and illustrate the difficulties in applying findings from disparate rice growing areas.

Ammonium sulfate was utilized as the inorganic-N source in this study; previous work has shown no difference in utilization and efficacy between this source and urea for flooded rice when properly managed (17), so the results reported here likely apply to the more commonly used urea as well. Proper management of an inorganic ammoniacal-N source is the most vital factor in its utilization (2,5,16).

It is common to find a stimulation of unlabeled soil-N availability or uptake due to labeled-N additions for flooded rice (2,4,5,15) and a wide range of other crops (1,7). Our finding is significant since the stimulation occurred both in terms of N availability and N uptake. Several explanations have been offered for this effect. One is that the addition of N to the soil stimulates plant activity and root growth to such an extent that available soil-N is more effectively utilized (1). This leads to an apparent priming effect where soil-N mineralization is not necessarily stimulated, but available N is more effectively taken up by the plants. Our finding that percent recovery of $(NH_4)_2SO_4$-N was stimulated by increasing rates of addition (Table 2) tentatively supports this explanation, but the fact that labeled-N recovery was unaffected by adding the two sources together, despite a stimulation in plant growth compared to the same treatments added alone, does not. This latter finding and the measurement of increased soil-N availability due to labeled-N additions (Fig. 1–3) indicate that the stimulation in soil-N uptake due to treatments was due to a priming effect, a soil phenomenon unrelated to plant growth.

The question remains, however, as to whether the priming effect is due to a real stimulation of soil-N mineralization, brought about through the effects of fertilizer salts on soil microbial activity (3,7), or whether it is an apparent effect due to the rapid immobilization of labeled N substituting for unlabeled soil-N in the mineralization-immobilization turnover process (8,9,24). An incubation study utilizing similar labeled treatments on this soil (24) found a relationship between labeled-N immobilization and the stimulation in soil-N mineralization, supporting the latter view. A field study with flooded rice (5), however, found no relationship between labeled-N immobilization and the stimulation of soil-N uptake due to treatments. More work is needed to clearly define the events occurring during the initial phases of flooding, which lead to this effect.

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